Global Change Impact Studies Centre (GCISC)
(A Body Corporate established under the GCISC Act 2013)

Subject: PREPARATION OF YEAR BOOK (2021-22) IN PURSUANCE OF RULE 25 OF RULES OF BUSINESS, 1973

Global Change Impact Studies Centre (GCISC) was first established as a development project in April 2002, with the mandate to undertake research on climate change and its impacts and potential remedies. Subsequently, GCISC's status was formalized through the passage of the GCISC Act 2013 by the Parliament (notified vide Gazette of Pakistan on 26 March 2013 as Act No. XVII of 2013). The Act defines GCISC as a body corporate governed by Board of Governors (BoG), which is chaired by the Federal Minister in-charge of the concerned Ministry dealing with the subject of climate change.

1. Mission Statement

To undertake scientific investigations of the phenomenon of climate change at regional and sub-regional levels and study its impact on various sectors of socio-economic development in order to prepare the country to meet threats to its water resources, agriculture, ecology, energy, health, bio-diversity etc.

2. Main Functions

Under the GCISC Act, the Centre is tasked with three functions, namely research, capacity building, and outreach and awareness:

a. **Research**: the research program is driven by national policy goals, namely protecting people against the impacts of climate change, promoting economic growth and sustainable development in a climate-constrained future, and honoring Pakistan's international commitments. To these ends, research is organized in three groups:

   - ***Climatology* and Environment**: using climate system models to predict future climate behavior in Pakistan, including monsoons, temperature, precipitation, and climate extremes.
   - ***Water Resources* and Glaciology**: using glacio-hydrological and water models to assess future behavior of glaciers, aggregate and seasonal flows in the Indus River System, and changes in the hydrological extremes across the country.
   - ***Agriculture, Forestry & Land Use:*** using crop simulation models to predict the impact of projected changes in temperature, precipitation, and water availability on agriculture and food security of the country and to assess the impacts on Forestry and Land Use.

b. **Capacity building**: imparting technical and communication skills to GCISC staff as well as students and climate scientists at other national research organizations and universities.

c. **Dissemination of research findings**: to the scientific community, planners, policymakers, and to the public at large, in order to raise awareness of climate change among policymakers as well as the citizenry.

3. Ongoing Research Activities

I. Climatology & Environment Section

The key research activities of Climatology & Environment Section revolve around following themes:

- Assessment of past climatic changes;
- Development of future climate projections for Pakistan by employing state-of-the-art high resolution Climate Models;
- Scientific Investigation and Prediction of Climatic Extremes by using modeling as well as statistical techniques;
- Simulation modeling to study monsoon dynamics and its associated impacts;
- Intra seasonal to inter decadal climate predictions;
- Development & Updating of GHG Inventory of Pakistan for Energy & Industrial Processes Sectors;

II. Water Resources & Glaciology Section

- Application of Machine Learning and Artificial Intelligence (AI) techniques to model Indus River System flows;
- Climate change analysis for the high elevation Karakoram region;
- Drought prediction in the Indus Basin as a climate adaptation strategy;
- Spatio-temporal assessment of climate change impacts on the UIB-cryosphere and variability of flows;
- Analysis of climate impact on the frequency and intensity of hydrological extreme events;
- Plausible Adaptation strategies in line with national Climate change and Water policies to ensure country's water security;
- Research dissemination (International and national science journals and books, newspaper articles, policy briefs, etc);
- Capacity building and awareness raising;

III. Agriculture, Forestry and Land Use Section

- Assess impacts of projected climate change on productivity of key agricultural crops in different climatic zones using crop models;
- Assess impacts on related areas, including productivity of forestry, grasslands, rangelands and fragile ecosystems (i.e., mountains, wetlands,

- coasts, and arid areas); livestock; and land degradation and deforestation, insect-pest infestation dynamics;
- Assess food security in the face of future climate changes and especially under reduced availability of irrigation water;
- Devise adaptation measures, including climate smart agriculture;
- Studies on water, food, energy and climate change nexus;
- Updating GHG emissions from agriculture, forestry and land use and waste sectors.

4. Achievements (Summary):

During the year, GCISC made significant contribution to the international scientific literature in the field of climate change and its associated impacts, and provided tangible inputs in a no. of research projects. It also organized a no. of workshops/seminars for information dissemination and awareness. The following is a summary of the accomplishments in 2021-22:

- Publication of key research findings in scientific journals = 17
- Contribution towards technical reports = 03
- Contributions in research projects = 05
- Organization of scientific activities/workshops/seminars for information dissemination and awareness = 12
- Effort on capacity building of GCISC young scientists through academic and specialized trainings and participation in conferences, workshops etc at International level (Nos) = 22
- Effort on capacity building of GCISC young scientists through academic and specialized trainings and participation in conferences, workshops etc at National Level (Nos) = 80
- Provision of training to university students across Pakistan in the field of climate change through summer internship program = 40
- GCISC experts delivered lectures as resource persons and imparted trainings to the researchers of various organizations.
- Muhammad Arif Goheer, Principal Scientific Officer/ Head- Agriculture and Coordination contributed to UNFCCC's Consultative Group of Experts (CGE) activities.
- Contributions to Pakistan's 1st Biennial Update Report submitted to UNFCCC in April 2022.
- Two scientists from GCISC are contributing as Lead Author for IPCC 6th Assessment Report.
- One GCISC scientist contributed as "Reviewer" to the GEO report on Cities.
- GCISC provided technical inputs in the preparation of Nationally Determined Contributions (NDCs) submitted to UNFCCC in October 2021.
- GCISC has been awarded contract by Ministry of Climate Change (MoCC) to contribute in various chapters of Third National Communication (TNC).
- Development of MRV platform for GHG Inventories & MRE platform for Adaptation tracking in Agriculture (Pilot basis).

5. **Salient Research Findings:**

a) 21st century precipitation and monsoonal shift over Pakistan and Upper Indus Basin (UIB) using high-resolution climate projections

The study investigates probable shift in the monsoon over Pakistan and Upper Indus Basin (UIB) by employing high resolution future projected data of climate models. The results indicate that June July August (JJA) precipitation over Upper Indus Basin (UIB) which also includes northern parts of Pakistan is projected to increase more under RCP8.5 as compared to RCP2.6. The results also show a projected expansion in monsoon area in UIB and northward shift of monsoon currents which corresponds with future precipitation changes in the area and hence indicates the penetration of monsoon system over UIB under higher warming scenario. The changes in monsoon precipitation and domain are related to the changes in wind circulation patterns at 850 hPa and 200 hPa atmospheric levels.

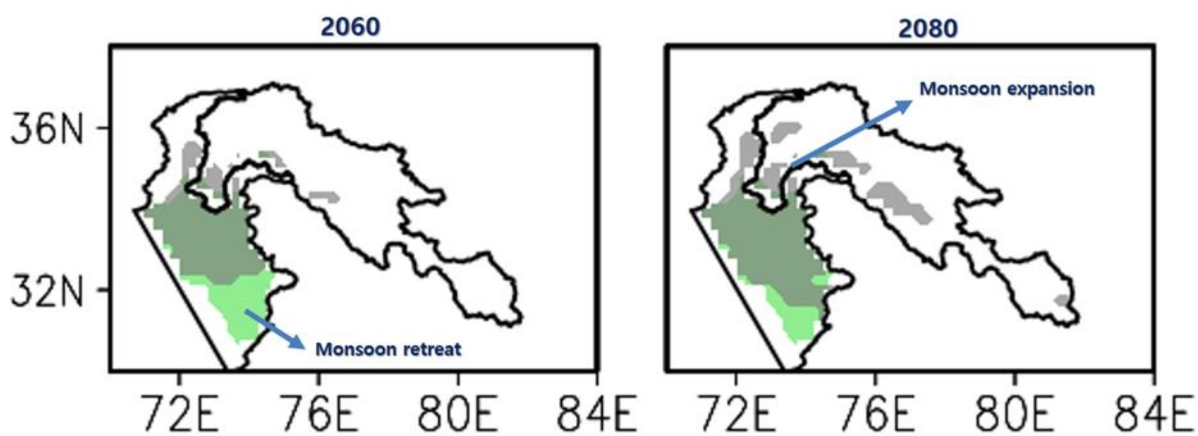


Fig. 1: *Future Projections of monsoon over Pakistan for near (2041-2070) and far (2071-2100) future periods under RCP2.6 and RCP8.5*

b) Projections of wind power density in Pakistan and adjacent regions

This study focuses on evaluation of wind power density over Pakistan and its provinces for four seasons defined as December January February (DJF), March April May (MAM), June July August (JJA), and September October November (SON). The results for whole Pakistan indicate that wind intensity was higher in JJA due to the influence of the active phase of the monsoon. In terms of subdomains, higher intense winds were reported in the provinces of Baluchistan and Sindh. For the same regions and season, the wind intensity is projected to increase (by ~1-1.5 m s-1), which leads to an increase in WPD of >20% in Baluchistan and 40% in Sindh under RCP8.5. We also project an increase in WPD in the eastern part of the country, but it will not be enough for wind energy generation

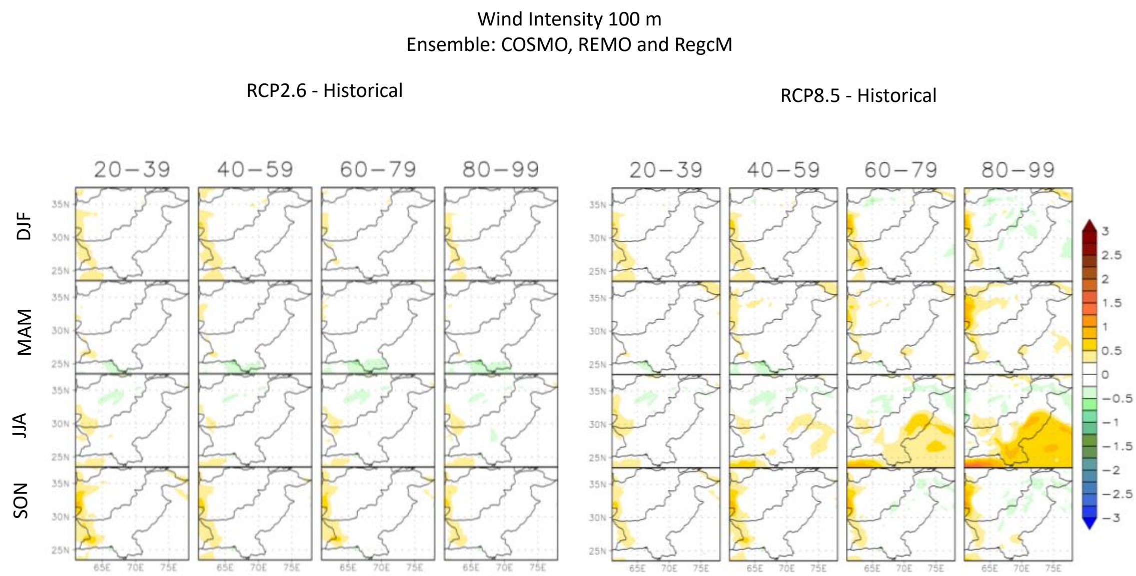


Fig. 2: *Wind intensity at 100m based on ensemble of COSMO, REMO, and RegCM under RCP2.6 and RCP8.5*

c) Climate change and spatio-temporal trend analysis of climate extremes in the homogeneous climatic zones of Pakistan

An analysis has been performed to evaluate the precipitation and temperature trends in the Karakoram region in recent past. The analysis showed a decrease in precipitation during 1991–2019 and an increase in temperature (maximum and minimum) during 2010–2019, which is consistent with the recently observed slight mass loss of glaciers related to the Karakoram Anomaly.

Variable	Season	Stations						
		Astore	Bunji	Chilas	Darosh	Gilgit	Gupis	Skardu
Difference of Average Temperature between 1991–2019 and 1962–1990	DJF	0.5082***	0.5404***	-0.5618***	0.7148***	0.8567***	-0.1942***	0.9677***
	MAM	0.6780***	0.5298***	-0.1238	0.6121***	0.7384***	-0.0823	0.7679***
	JJA	-0.2891***	-0.9248***	-0.1220**	-0.0137	-0.4890***	-1.4199***	-0.2753***
	SON	0.3906***	-0.3328***	-0.2666**	0.5326***	0.1510	-0.0157	0.0041
	Overall	**0.3208****	**-0.0489**	**-0.2671****	**0.4600*****	**0.3121****	**-0.4303*****	**0.3642****
Precipitation	DJF	0.2720***	0.1299***	0.1980***	0.1877**	-0.2388***	0.1456***	0.2984***
	MAM	-0.1176	-0.0347	0.0705	-0.3605***	-0.1836***	0.5083***	0.0513
	JJA	0.1502***	0.1719***	-0.2282**	0.03797	-0.3112**	0.3367***	0.0850***
	SON	-0.0786	0.0604***	0.0024	0.1001	-0.0727*	0.1046**	-0.3861**
	Overall	**0.0558**	**0.0817****	**0.0098**	**-0.0099**	**-0.2017****	**0.2749*****	**0.0119**

Note: Where "***", "**" and "*" indicate significance of the test at 1%, 5% and 10% level of significance.
DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November.

https://doi.org/10.1371/journal.pone.0271626.t004

Fig.3: *Precipitation and temperature change trends in selected stations in Gilgit Baltistan region.*

d) An Overview of Groundwater Monitoring through Point-to Satellite-Based Techniques

Groundwater supplies approximately half of the total global domestic water demand. It also complements the seasonal and annual variabilities of surface water. Monitoring of groundwater fluctuations is mandatory to envisage the composition of terrestrial water storage. This research provides an overview of traditional techniques and detailed discussion on the modern tools and methods to monitor groundwater fluctuations along with advanced applications. The groundwater monitoring can broadly be classified into three groups. The first one is characterized by the point measurement to measure the groundwater levels using classical instruments and electronic and physical investigation techniques. The second category involves the extensive use of satellite data to ensure robust and cost-effective real-time monitoring to assess the groundwater storage variations. Many satellite data are in use to find groundwater indirectly. However, GRACE satellite data supported with other satellite products, computational tools, GIS techniques, and hydro-climate models have proven the most effective for groundwater resources management. The third category is groundwater numerical modeling, which is a very useful tool to evaluate and project groundwater resources in future. Groundwater numerical modeling also depends upon the point-based groundwater monitoring, so more research to improve point-based detection methods using latest technologies is required, as these still play the baseline role. GRACE and numerical groundwater modeling are suggested to be used conjunctively to assess the groundwater resources more efficiently.

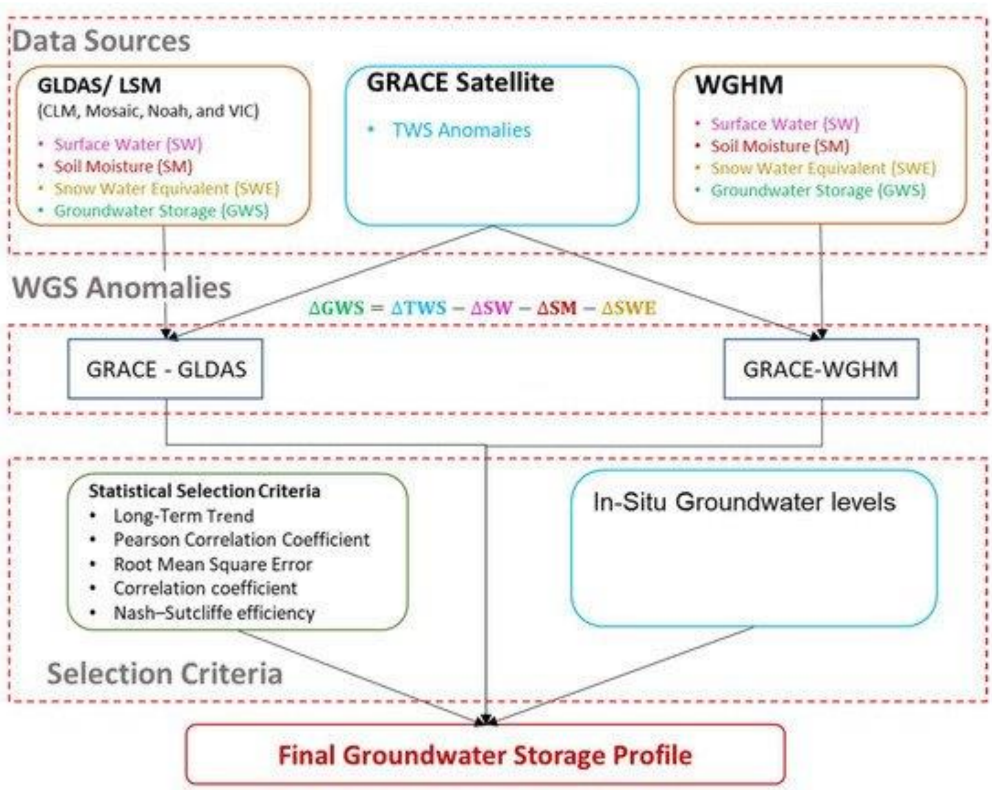


Fig. 4: *GRACE–GLDAS and GRACE–WGHM processing to get Groundwater storage from GRACE satellite data*

e) **Hydrological Interpretation of Machine Learning Models for 10-daily streamflow simulation in Climate Sensitive Upper Indus Catchments**

Machine learning for hydrologic modeling has seen significant development and has been suggested as a valuable augmentation to physical hydrological modeling, especially in data scarce catchments. In Pakistan, surface water flows predominantly originate from the transboundary Upper Indus sub-catchments of Chenab, Jhelum, Indus and Kabul rivers. These are high elevation data scarce catchments and generated streamflows are highly seasonal and prone to climate change. Given the catchment characteristics, there is utmost need to develop machine learning models that are hydrologically robust. Thus, the current study besides evaluating the potential of three machine learning models for streamflow simulation also focused on the hydrologic interpretation of machine learning models using SHapley Additive exPlananations(SHAP).XGBOOST, RandomForest and Classification and Regression Trees(CART) were evaluated. All of these models performed well and range of R^2 and Nash Efficiency for all three models lies between 0.65 to 0.90. Our study's most crucial contribution is SHapley Additive exPlananations (SHAP) method which gives extensive insights into the influence of each variable on simulated streamflow. SHAP analysis highlighted the significance of minimum temperature in high elevation zones for both Indus and Chenab catchment where streamflows are dominated by snow and glacier melt. We strongly believe that the findings of this study will promote the use of SHAP analysis for streamflow forecasting in data scarce and high elevation catchments in Pakistan.

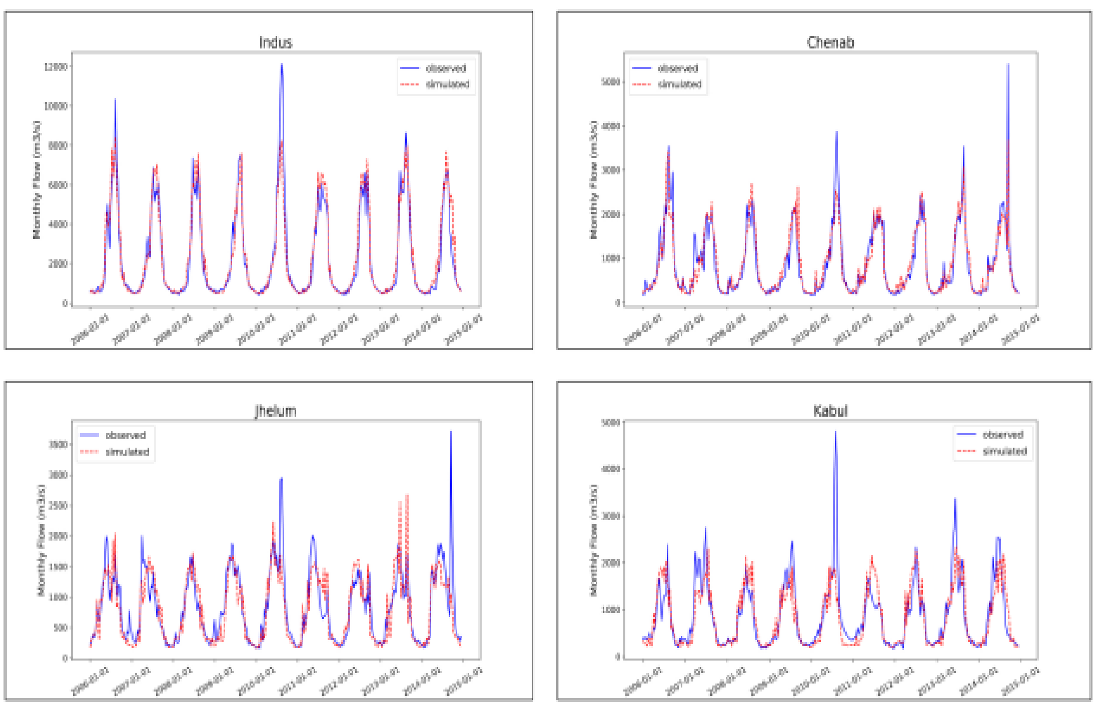


Fig. 5: *Simulated and observed hydrographs of XGBoost model at outlets of Upper Indus catchments of Pakistan: a) Indus at Tarbela b) Jhelum at Mangla c) Chenab at Marala and d) Kabul at Nowshera*

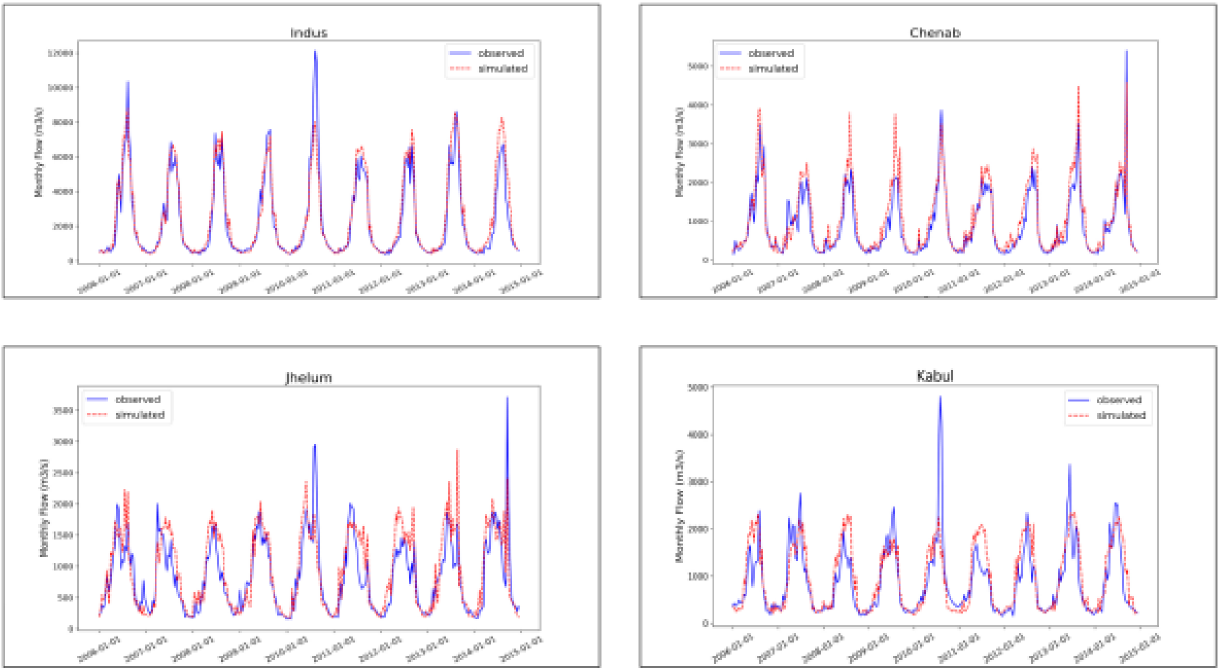


Fig. 6: *Simulated and observed hydrographs of Random Forest model at outlets of Upper Indus catchments of Pakistan: a) Indus at Tarbela b) Jhelum at Mangla c) Chenab at Marala and d) Kabul at Nowshera*

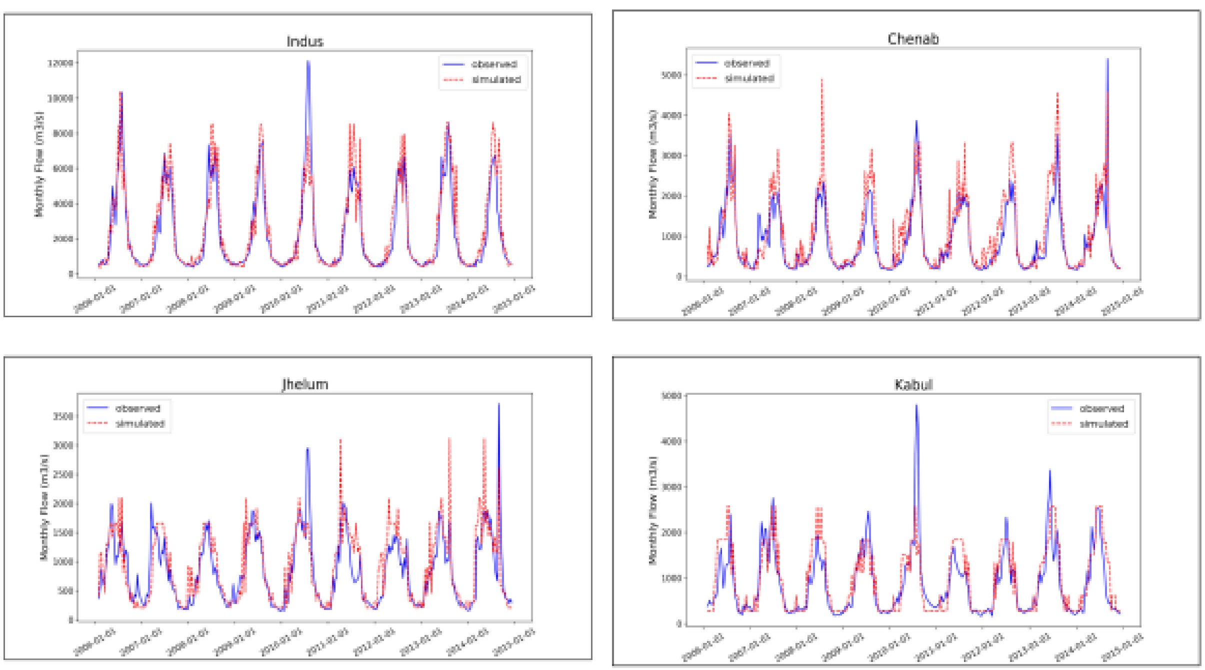


Fig. 7: *Simulated and observed hydrographs of CART model at outlets of Upper Indus catchments of Pakistan: a) Indus at Tarbela b) Jhelum at Mangla c)Chenab at Marala and d)Kabul at Nowshera*

f) Climate-Induced Shifts in Irrigation Water Demand and Supply during Sensitive Crop Growth Phases in South Asia

This study investigated climate-induced shifts in irrigation water demand and supply of the major staple and water-intensive crops (wheat and rice) in the Indus, Ganges and Brahmaputra (IGB) river basins of South Asia. It explores the usage of irrigation water during climate-sensitive crop growth phases (i.e., vegetative and reproductive which required ~ 60% of the total crop water demand), supposed to be crucial for long-term integrated crop water management. A hydrology vegetation model LPJmL is forced with an ensemble of eight downscaled (5 arc-min) GCM's using a mix of two emission scenarios i.e., RCP4.5-SSP1 and RCP8.5-SSP3. To investigate phase-specific shifts in crop water use during the period 1981-2100, trend analysis is performed. It shows a significant ($p<0.001$) increase in irrigation water demand during the vegetative phase of wheat (6 mm) and reproductive phase of rice (26 mm) and a decrease during the reproductive phase of wheat (13 mm) and vegetative phase of rice (11 mm) in selected study sites. The large decrease in projected irrigation demand of wheat can be explained by a shortening of growing season length as a result of rising temperatures and increased precipitation. Whereas, an increase in irrigation demand for rice is combined effect of higher temperatures and less precipitation during the reproductive phase in the region. At the same time, irrigation supply by surface water and groundwater is likely to change in future as a result of warmer and drier growing period, causing a significant increase in groundwater irrigation, mainly for rice. Our major research findings show the importance of crop water assessments during the sensitive crop growth phases of wheat and rice which varies in space and time. Including crop phase-specific climate impact assessments of regional and global projection will help to improve the existing crop-water management strategies and adaptation practices in the region.

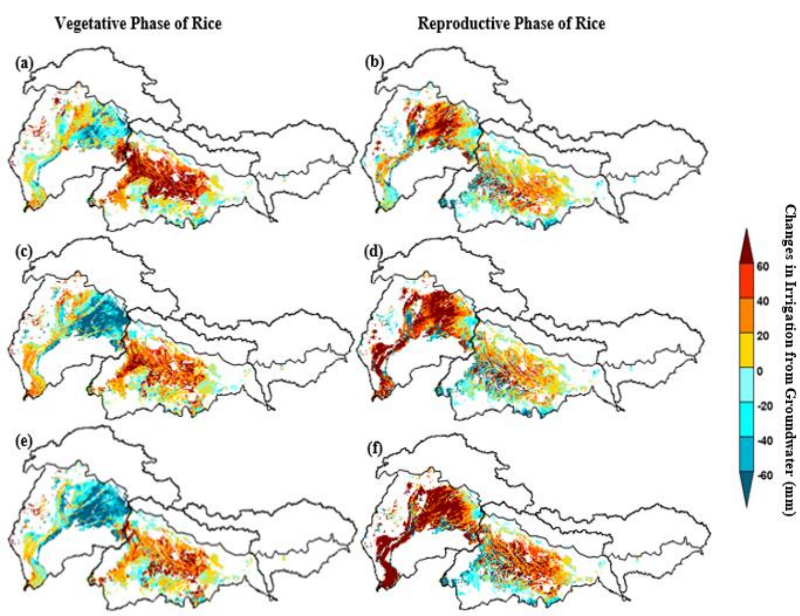


Fig. 8: *Projected changes in irrigation from groundwater (mm) during the vegetative (a, c, e) and reproductive (b, d, f) phases of rice over the whole IGB river basins for three reference periods i.e., 2011-2040 (a-b), 2041-2070 (c-d), and 2071-2100 (e-f). Changes are relative to the 30 years mean groundwater supply for the control period 1981-2010 (Fig. S1b). Positive values indicate the groundwater supply is increasing relative to the control period.*

g) GIS-based Spatio-Temporal Assessment of Forest Cover Change and Carbon Sequestrations of District Abbottabad, Pakistan

This study was conducted to analyze Land Use Land Cover (LULC) changes and Carbon stock assessment over Abbottabad district, Pakistan. The result shows an overall increase of 3.17%, 17.24%, and 7.24% in the forest, vegetation, and build-up areas, respectively; whereas water-bodies and others (barren land) has decreased significantly by 0.69% and 26.96% respectively (**Figure 9**). Results revealed that carbon sequestration increase as the year passes due to afforestation in the study area. From 1986 to 2004 carbon sequestration decreased by 12.93%, while in 2002 – 2014 carbon sequestration increased by 19.54% between 2014 – 2019 (**Figure 10**).

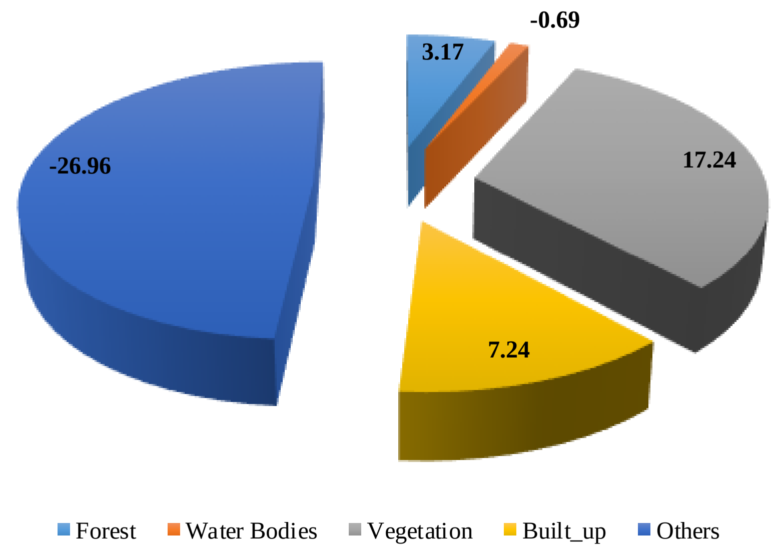


Fig. 9: *Net percentage Change in Land Use Land Cover (1986 – 2019)*

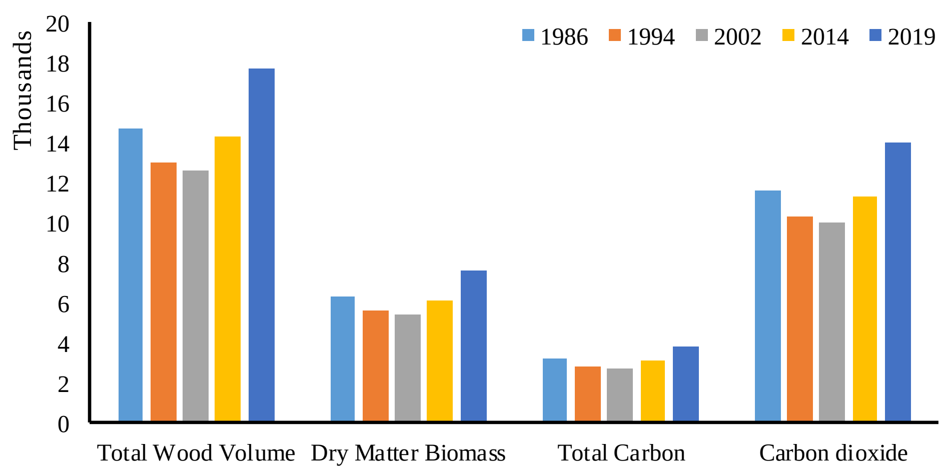


Fig. 10: *Trend of total wood volume, Dry matter biomass, total carbon, carbon dioxide during 1986 – 2019*

h) Implication of Remote Sensing Data under GIS Environment for Appraisal of Irrigation System Performance

The substantial contribution of agriculture sector in Pakistan's economy is presently on threat due to water shortage, unequal distribution and access to water resources. Efficient and integrated use of water by improving irrigation management & delivery can reduce this menace. An appraisal of system performance helps in managing the system. This needs real-time data which is usually expensive and difficult to collect for longer periods. Remotely sensing and Geographic Information System have the potential to overcome it. This manuscript presents a methodology to assess irrigation system performance by determining commonly used indicators and successfully applied on main canal system. Remotely sensed and conventional data were used to derive crop water requirement, availability and its spatial distribution. Potential water requirement of the area was found 401.66 million cubic meters (MCM) and available canal water supply was 247.14 MCM, thus having shortage of 38%. Water consumption of wheat was estimated by remote sensing to be 243.41 MCM which was comparable to the available canal water supply confirming accuracy of the proposed method. *Adequacy* of the system was found to be 74 % while its *reliability* varied from 35-73% throughout the wheat season. The coefficient of variance (Cv) showed that the irrigation system under this study was unreliable during the wheat season. Performance in *equity* terms revealed that head areas of irrigation channels were receiving more water supplies than the tail areas. Strong correlation was found between crop yields and water supplies i.e., crop yield was strongly dependent on water supplied (R2=0.80).

***Table 1** - Range of water quantities consumed under various segregations of land use.*

Segregated groups	Description of area	water consumption (mm day^{-1})	
		First month	Second month
A	Not cultivated	0.00-0.28	0.00-0.20
B	in stress	0.28-2.47	0.20-1.26
C	No stress	2.47-3.55	1.26-2.42

i) Effect of Zero and Minimum Tillage on Cotton Productivity and Soil Characteristics under Different Nitrogen Application Rates

Long-term conservation tillage and straw incorporation are reported to improve the soil health, growth, and yield traits of crops; however, little is known regarding the optimal nitrogen (N) supply under conservation tillage with straw incorporation. The present study evaluated the effects of conservation tillage practices (ZTsas: zero tillage plus wheat straw on the soil surface as such, and MTsi: minimum tillage plus wheat straw incorporated) and different N application rates (50, 100, 150, and 200 kg ha^{-1}) on the yield and quality traits of cotton and soil characteristics in a five-year field experiment. The results showed that ZTsas produced a higher number of bolls per plant, boll weight, seed cotton yield, 100-seed weight, ginning out-turn (GOT), fiber length, and strength than MTsi. Among different N application rates, the maximum number of bolls per plant, boll weight, seed cotton yield, GOT, 100-seed weight, fiber length, strength, and micronaire were recorded at 150 kg N ha^{-1}. Averaged over the years, tillage × N revealed that ZTsas had a higher boll number plant^{-1}, boll weight, 100-seed weight, GOT, fiber length, and strength with N application at 150 kg ha^{-1}, as compared to other tillage systems. Based on the statistical results, there is no significant difference in total soil N and soil organic matter among different N rates. Further, compared to MTsi, ZTsas recorded higher soil organic matter (SOM, 8%), total soil N (TSN, 29%), water-stable aggregates (WSA, 8%), and mean weight diameter (MWD, 28.5%), particularly when the N application of 150 kg ha^{-1}. The fiber fineness showed that ZTsas had no adverse impact on fiber fineness compared with MTsi. These results indicate that ZTsas with 150 kg N ha^{-1} may be the optimum and most sustainable approach to improve cotton yield and soil quality in the wheat–cotton system.

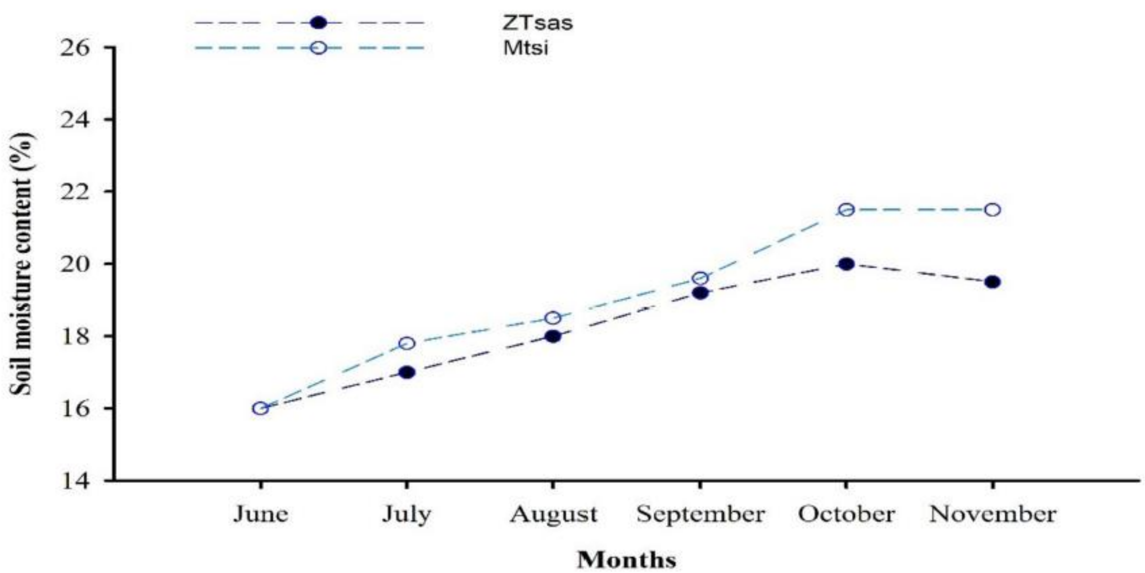


Fig. 11: *Effect of tillage treatments (ZTsas, zero tillage with straw retention; MTsi, minimum tillage with straw incorporation) on soil moisture content during the last year of experiment (2015-2016).*

j) The implication of remotely sensed vs climate data in assessing crop water ingestion using machine learning

Pakistan possesses an agriculture-based economy and in general, its agricultural production is relatively increased during the last decade. Pakistan's agricultural industry is a major contributor to its GDP. It fulfills almost all of the 90% food and fiber requirements. Still, there is a big gap when compared with many countries of the world due lacks to its poor resource management. Irrigated agriculture in Pakistan consumes 93 percent of the available water resources whereas more than 60 percent of irrigation water is lost during the conveyance and application in the field. The major reason for application losses is the lack of knowledge about irrigation scheduling. Other factors are the ever-growing population, urbanization, industrialization, and inadequate storage. Estimation of Crop Water Requirement (CWR) is a basic tool in water resources management which is based on crop evapotranspiration (ET) estimation. Several methods for estimation of crop ET are being used by various researchers, which have their own deficiencies. Under this study, two well known and most reliable methods i.e., SEBAL and CROPWAT, which use satellite data and climatic data respectively, were tested. Both methods were applied to the estimation of wheat crop ET on the entire district of Peshawar and results were compared to provide the sound basis for ET estimation. It has been observed that both results were compared able with minor deviations. CROPWAT requires a lot of climatic parameters that are difficult to collect due to the involvement of huge labor and instrumentations. To avoid the collection of these data, satellite-based estimation of crop ET through energy balance equation is easy and it gives an actual on-ground estimation of crop ET. This study testifies that satellite base ET estimation is cost-effective, easy to apply and gives more reliable results.

k) Assessing drought and its impacts on wheat yield using remotely sensed observations in rainfed Potohar region of Pakistan

This study aims to assist the decision-making process for drought monitoring and yield predictions, as it informs drought assessment and its impacts on crop yield using drought and vegetation indices along with climate and crop yield data. This research quantifies recurrent drought events for Rubi (wheat crop) season (November-April) from 2000 to 2018 in the Potohar region using indices such as; Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI) along with climatic parameters i.e., mean temperature, rainfall and soil moisture. Results show three moderate (2000-01, 2001-02, 2009-10) and two weak (2011-12, 2017-18) drought events are identified using SPI, whereas two more drought events (2007-08 and 2016-17) are noticed when vegetation indices are used. Artificial Neural Network (ANN), a multilayer perception (MLP) model is applied afterwards to see the individual impact of each study parameter on wheat yield. Soil moisture is found to impact yield by 100 %, temperature as 74 %, rainfall as 61 % and then rest of the indices.

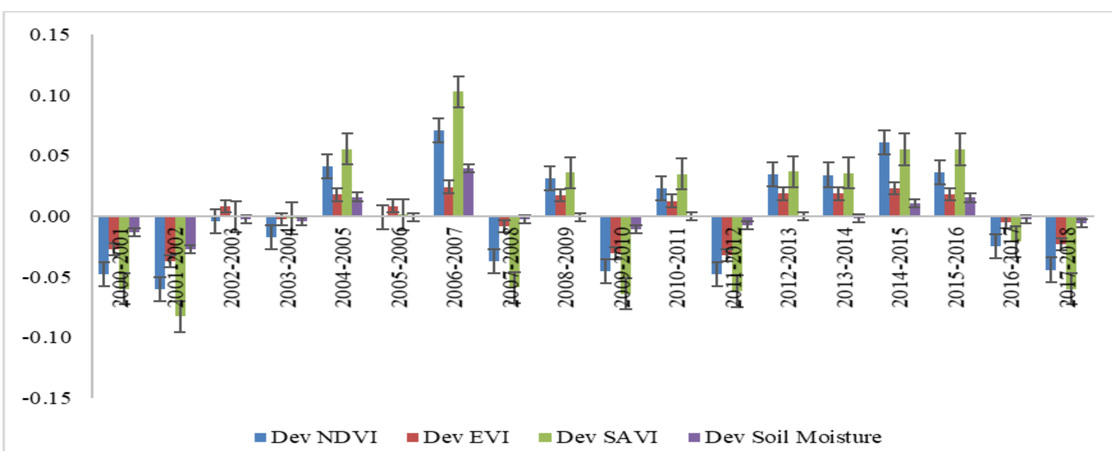
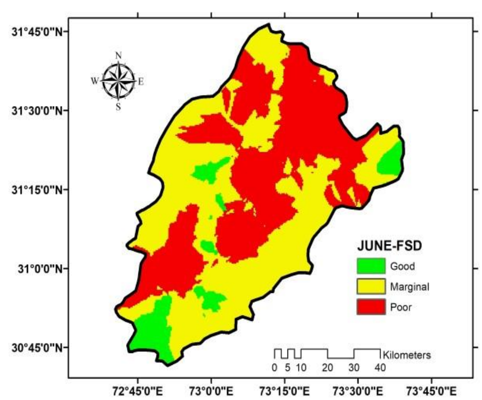


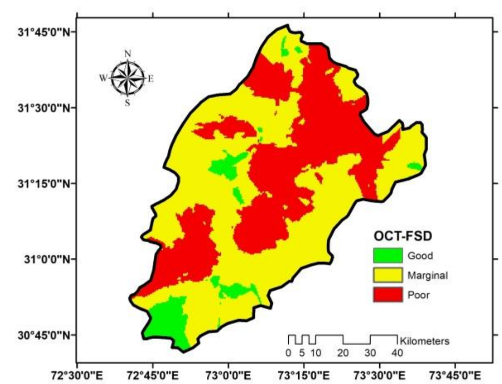
***Fig. 12:** Deviation of NDVI, EVI, SAVI and soil moisture in the Potohar region during Rubi season from 2000-2018*

l) Geostatistical investigation of groundwater quality zones for its applications in irrigated agriculture areas of Punjab (Pakistan)

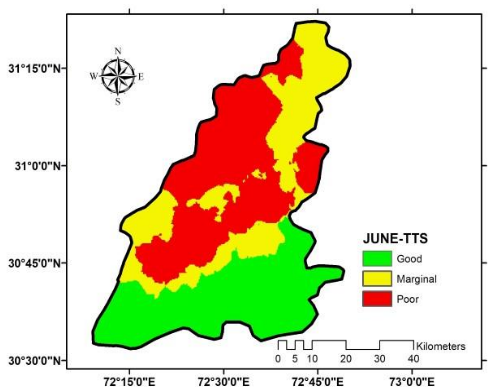
This study was carried out in Faisalabad (FSD) and Toba-Tek Singh (TTS) districts of Punjab, Pakistan to check its suitability for irrigation with three major parameters (i.e. EC, SAR, and RSC). Geo-statistical water quality analysis was carried out using the GS+ and ArcGIS includes three basic components normalized histograms, semivariograph, and Kriging. A hydro-economic model was applied to observe the impact of groundwater quality on crop yield and farmers' income. It was found that the percent area under a good groundwater quality zone in FSD was about 25% fewer than TTS. In FSD, the majority area of the aquifer was under marginal (50-55%) to poor (39-44%) quality groundwater zones and salinity and sodicity are major threats depicted by EC and RSC, respectively. In TTS district, salinity was the only major risk to groundwater quality as about 45% area was under poor quality zone. The overall aquifer's area under about good (~33%), marginal (~29%) and poor (~38%) quality groundwater zone. Comparing the economic models in two districts using the different quality water it was found that the BCR (Benefit Cost Ratio) was recorded 2.31, 2.13 and 1.73 in FSD district while in TTS district the BCR was 2.35, 2.09 and 1.58 for good, marginal and poor quality zone, respectively.



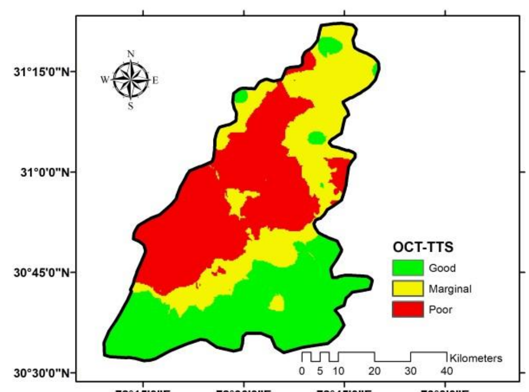
(a) Faisalabad district (Pre-monsoon)



(b) Faisalabad district (Post-monsoon)



(c) Tobatake Singh district (Pre-monsoon)



(d) Tobatake Singh district (Post-monsoon)

Fig. 13: *Spatial variation of overall water quality for irrigation*

m) Projections of wind power density in Pakistan and adjacent regions

This work focuses on the wind energy in Pakistan projected by 3 regional climate models (RCMs), namely COSMO-CLM, REMO and RegCM4, nested in different global climate models from the Coupled Model Intercomparison Project 5. Five time-slices (1995-2014, 2020-2039, 2040-2059, 2060-2079 and 2080-2099) and 2 scenarios (RCP2.6 and RCP8.5) were analyzed. Wind energy studies are based on 2 variables: wind intensity and wind power density (WPD). WPD is a measure of the wind energy produced by turbines installed above the surface, currently at 100 m height. Before computing WPD, a simple bias correction was applied to the model data. Considering all of Pakistan, wind intensity was higher in June, July and August due to the influence of the active phase of the monsoon. In terms of subdomains, higher intense winds were reported in the provinces of Balochistan and Sindh. For the same regions and season, the wind intensity is projected to increase (by ~1-1.5 m s^{-1}), which leads to an increase in WPD of >20% in Balochistan and 40% in Sindh under RCP8.5. We also project an increase in WPD in the eastern part of the country, but it will not be enough for wind energy generation. Our research findings can be useful for entrepreneur investors in wind energy.

Workshops Organized:

1. Online Workshop on F-Gases jointly organized by GCISC, GIZ & CITEPA - 1 July 2021
2. Training workshop on GHG Emissions / Carbon Accounting in Forestry sector organized jointly by MoCC / IUCN / GCISC / REDD+ at Hotel Margala Islamabad - 31 Aug - 1 Sep 2021
3. Workshop on Development of MRV System for Greenhouse Gas Inventories in Punjab, Pakistan jointly organized by GCISC / MoCC / CITEPA / GIZ at Serena Hotel, Islamabad on 20 September 2021
4. WORKSHOP on “Development of M & E System for Adaptation Tracking (Agriculture) in Pakistan” jointly organized by GCISC / MoCC, CITEPA and GIZ-Pakistan at Serena hotel, Islamabad on 21 September 2021
5. Workshop on "Monsoon Variability and Extremes in Changing Climate" organized by GCISC at Islamabad from 12-14 October 2021
6. RISQ Platform Training Workshop on “Official Launch & Training of Monitoring and Evaluation (M&E) System for Adaptation Tracking (Agriculture Sector) in Pakistan” jointly organized by GCISC and CITEPA at Islamabad Hotel on 23 November 2021
7. Training of Training on RISQ Platform Workshop on “Official Launch & Training of Monitoring and Evaluation (M&E) System for Adaptation Tracking (Agriculture Sector) in Pakistan” jointly organized by GCISC and CITEPA at Islamabad Hotel on 24 November 2021.
8. Provincial Training Workshop on "The RISQ Climate Change Adaptation M&E Tracking Tool (Agriculture Sector)" jointly organized by GCISC and CITEPA at Luxus Grand Hotel, Lahore from 29-30 November 2021
9. Provincial Training Workshop on "The RISQ Climate Change Adaptation M&E Tracking Tool (Agriculture Sector)" jointly organized by GCISC and CITEPA at PC Hotel, Karachi from 02-03 December 2021
10. National Stakeholder’s Consultation Workshop on Mainstreaming Climate Smart Agriculture under Workshop organized on "Pathways to Strengthening Capabilities for Climate Smart Agriculture in Pakistan" - 22 December, 2021 at Islamabad Hotel
11. Workshop on “Responding to Climate Change: Adaptation and Mitigation in Agriculture” in Training program on “Climate and resilient and water smart agriculture” organized by PARC-NARC/GCISC at NARC Islamabad from 29-30 December 2021
12. Workshop on Climate Change and development of IT based Digital Monitoring, Reporting and Verification System for Climate Smart Rice to the Ministry of Climate Change, Islamabad jointly organized by GCISC & Helvitas at Hotel Margala Islamabad on 23 June 2022

Dissemination of R&D Findings:

Research Papers in National/ International Journals and Reports:

1. GIS-based spatio-temporal assessment of forest cover change and carbon sequestrations of District Abbottabad, Pakistan. Journal of Water and Climate Change, 13(8), 2962-2971. Goheer, M. A., Hassan, S. S., Gul, K., Waqar, M., & Parveen, N. (2022)
2. Effect of Zero and Minimum Tillage on Cotton Productivity and Soil Characteristics under Different Nitrogen Application Rates. Niamat Ullah Khan, Aftab Ahmad Khan, Muhammad Arif Goheer
3. The implication of remotely sensed vs climate data in assessing crop water ingestion using machine learning. Aftab Ahmad Khan, Muhammad Arif Goheer, Mubashir Ali, Dr. Sultan Ahmad Rizvi
4. An Overview of Groundwater Monitoring through Point-to Satellite-Based Techniques by Amjad Masood, Muhammad Atiq Ur Rahman Tariq, ORCID, Muhammad Zia Ur Rahman Hashmi, Muhammad Waseem, Muhammad Kaleem Sarwar, Wasif Ali, Rashid Farooq ORCID, Mansour Almazroui, ORCID and Anne W. M. Ng (Feb 2022)
5. Hydrologic Interpretation of Machine Learning Models for 10-dailystreamflow simulation in Climate sensitive Upper Indus Catchments, Haris Mushtaq, Taimoor Akhtar, Muhammad Zia-ur-Rahman Hashmi, and Amjad Masood (2022)
6. Geostatistical investigation of groundwater quality zones for its applications in irrigated agriculture areas of Punjab (Pakistan), Environmental Earth Sciences (2022) 81:91
7. Implication of Remote Sensing Data under GIS Environment for Appraisal of Irrigation System Performance. Sultan Ahmad Rizvi, Afeef Ahmad, Muhammad Latif, Abdul Sattar Shakir, Aftab Ahmad Khan, Waqas Naseem & Muhammad Riaz Gondal
8. Assessing drought and its impacts on wheat yield using remotely sensed observations in rainfed Potohar region of Pakistan. Muhammad Ijaz, Qudsia Zafar, Aftab Ahmad Khan, Sher Shah Hassan. Environment, Development and Sustainability (2022)
9. “Shifts in Irrigation Water Demand and Supply Pattern During Sensitive Crop Growth Phases in South Asia". Qurat-ul-Ain Ahmad, Eddy Moors, Hester Biemans, Nuzba Shaheen, Ilyas Masih, Muhammad Zia ur Rahman Hashmi. (under review)
10. Variability in runoff and responses to land and oceanic parameters in the source region of the Indus River. Ecological Indicators, 140, 109014. Hussain, A., Cao, J., Shaukat Ali., Ullah, W., Muhammad, S., Hussain, I., ... & Zhou, J. (2022).
11. Climate change and spatio-temporal trend analysis of climate extremes in the homogeneous climatic zones of Pakistan during 1962-2019. PloS one, 17(7), e0271626. Khan, F., Shaukat Ali., Mayer, C., Ullah, H., & Muhammad, S. (2022).
12. Observed trends and variability of seasonal and annual precipitation in Pakistan during 1960–2016. International Journal of Climatology. Hussain, A., Cao, J., Shaukat Ali., Muhammad, S., Ullah, W., Hussain, I., ... & Zhou, J.

13. Early summer surface air temperature variability over Pakistan and the role of El Niño–Southern Oscillation teleconnections. International Journal of Climatology. Rashid, I. U., Abid, M. A., Almazroui, M., Kucharski, F., Hanif, M., Shaukat Ali., & Ismail, M. (2022).
14. Non-uniform changes in different daily precipitation events in the contiguous United States. Weather and Climate Extremes, 100417. Li, M., Sun, Q., Lovino, M. A., Shaukat Ali., Islam, M., Li, T., ... & Jiang, Z. (2022).
15. Projections of wind power density in Pakistan and adjacent regions. Climate Research, 85, 177-192. Reboita, M. S., Kiani, R. S., Shaukat Ali., & Khan, T. (2021).
16. 21st century precipitation and monsoonal shift over Pakistan and Upper Indus Basin (UIB) using high-resolution projections. Science of The Total Environment, 797, 149139. Shaukat Ali., Reboita, M. S., & Kiani, R. S. (2021).
17. Wavelet coherence of monsoon and large-scale climate variabilities with precipitation in Pakistan. A Hussain, J Cao, S Ali, W Ullah, S Muhammad, I Hussain, H Abbas, ... International Journal of Climatology
18. Preparation of GHG Inventory 2017-18.
19. Contribution to the preparation of Pakistan updated NDC's submitted to UNFCCC in November, 2021.
20. Contribution to the preparation of Biennial Update Report (BUR1) submitted to UNFCCC by MoCC in April 2022.

A. Capacity Building:

Capacity building is an important component of GCISC's activities. Climate change still is an evolving science. The new concepts, tools and methodologies for impact assessment emerge quite frequently. Capacitate the Centre's researchers as well as other institutions with upcoming technologies and skills is imperative for quality research and action.

During 2021-22, the Centre's scientists participated in a number of national/ international training workshops and acquired new skills ranging from climate science, climate modeling, seasonal forecasting, early warning systems, drought monitoring and assessments, hydrological, crop simulation and water management modeling, water surface runoff analysis, water-food-energy nexus, to earth observation systems, space technology and RS/GIS tools. The acquired skills are being used for the ongoing and planned research activities at the Centre. GCISC's scientists also contributed as resources persons in workshops and seminars organized by various organizations.

Forty (40) students from National University of Science and Technology (NUST), Islamabad, Bahria University, Islamabad, PMAS-Arid Agriculture University Rawalpindi. University of Agriculture, Faisalabad and University of Engineering & Technology (UET) Peshawar attended GCISC as Interns for a period of 2-3 months. The Centre's researchers provided them orientation lectures on climate science, modeling and other analytical skills and supervised them for various studies assigned to them by their university teachers and GCISC researchers.

The Centre is also organizing a series of lectures called as 'Friday Seminar' in which GCISC's own as well as researchers from other institutions deliver lectures on the latest ongoing research and present studies on the aspects of climate sciences, sectoral impacts and response strategies.

B. Mass Awareness / Media Appearance:

The Centre's scientists published several news articles in the leading national newspapers on the various aspects of climate science and its associated impacts on water, agriculture, and forestry. Scientists also provided interviews and responses on the ongoing issues of heatwaves, glacier melting, monsoon havoc, food insecurity, wheat crisis, effective irrigation water management and other allied issues pertaining to climate change. A detail of activities is as follows:

Newspaper Articles:

- Article on Climate Hotspots and Policy- The News on 13 Jul 2021;

- Article on Spatial Shift in Monsoon- The News on 9 Oct 2021;
- Article on COP26 - Glass half-full or half-empty- The News on 23 Nov 21;
- Article on The How to deal with heatwaves- The News on 16 Jun 22.

Climate Change Awareness on Electronic Media:

- GCISC Message on Climate Change awareness broadcasted live on SUCH TV-31 Dec 2021;
- GCISC Scientist Live broadcast on Pakistan Television News (PTV News) and FM98 Radio Dosti Channel - 16 May 2022;
- SAMMA TV broadcasted GCISC's paper's findings during the May 2022 heatwave. The study has been published in The International Journal of Climatology.

Briefings to Institutions:

- Medical Doctors of Aga Khan Medical University, Karachi were briefed on the aspects of Climate Change on health - 07 March 2022;
- Participants of the Akhtar Hameed Khan Niazi National Commission for Rural Development (NCRD) visited GCISC and were briefed on Climate Change – 11 May 2022.

C. Inputs for parliamentary Business

GCISC, being the research arm of the Ministry of Climate Change, frequently provides technical inputs on climate change, impacts and response strategies for parliamentary business. In this regard GCISC provided responses to National Assembly and Senate questions and also contributed to the proceedings of the standing committees on the concerns of climate change.